IMPROVING ON THE NETWORK LIFETIME OF CLUSTERED-BASED WIRELESS SENSOR NETWORK USING MODIFIED LEACH ALGORITHM

SALTIHIE BIN ZENI

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For my beloved wife Rabuyah Binti Sahmat

&

My mother and father

For your infinite and unfading love, sacrifice, patience, encouragement and best wishes

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In the name of Allah, the Most Gracious and the Most Merciful.

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ABSTRACT

Wireless sensor networks (WSNs) composed from a large number of sensor node with the ability to sense and process data in the physical world in a timely manner. The sensor nodes contain a battery constraint which limit the network lifetime. Due to energy constraints, the deployment of WSNs will required advance techniques to maintain the network lifetime. A clustering based routing algorithm called Low-Energy Adaptive Clustering Hierarchy (LEACH) was proposed as a solution for low power consumption. This document is a study about LEACH algorithm where the implementation was done using OMNeT++ network simulator to study the performance of this algorithm in term of network lifetime. OMNeT++ was selected as a simulator because it provides some important features for this project like very good scalability unlike other simulators do. During this study, LEACH algorithm shows some drawbacks that need an improvements to overcome it as to improve the performance. Then, the modified LEACH algorithm was proposed where the improvement was done in cluster head selection based on LEACH. In cluster head selection, modified LEACH taking into account the residual energy of each node for calculation of the threshold value for next round. Meanwhile in LEACH, the cluster head selection was based on distributed algorithm. Both of these protocols was implemented in network simulator to compare the performance. This study shows that there were a better performance achieved by modified LEACH depends on the results obtained.

ABSTRAK

Rangkaian sensor tanpa wayar terdiri daripada sejumlah besar nod sensor dengan kebolehan untuk mengesan data dalam dunia fizikal tepat pada masanya. Nod sensor dikuasakan oleh bateri yang menyebabkan terdapat had untuk jangka hayat rangkaian. Disebabkan oleh masalah tenaga, penempatan rangkaian sensor tanpa wayar ini memerlukan teknik yang baik bagi mengekalkan jangka hayat rangkaian. Protokol yang berasaskan kepada algoritma kelompok yang dikenali sebagai Low-Energy Adaptive Clustering Hierarchy (LEACH) telah diperkenalkan sebagai penyelesaian untuk penggunaan tenaga yang rendah. Dokumen ini ialah kajian mengenai algoritma LEACH di mana perlaksanaannya di lakukan dengan menggunakan simulator rangkain OMNeT++ untuk mengkaji prestasi algoritma ini dalam bentuk jangka hayat rangkaian. OMNeT++ dipilih sebagai simulator kerana ia menyediakan ciri-ciri yang penting untuk projek ini seperti skalabiliti yang baik tidak seperti simulator yang lain. Dalam perlaksanaan kajian ini, algoritma LEACH menunjukkan beberapa kelemahan yang memerlukan penambahbaikan untuk mengatasinya serta meningkatkan prestasinya. Kemudian, LEACH yang diubahsuai telah diperkenalkan dimana penambahbaikan telah dilaksanakan dari segi pemilihan ketua kelompok yang berdasarkan kepada LEACH. Dalam pemilihan ketua kelompok, LEACH yang di ubahsuai mengambil kira baki tenaga setiap nod untuk pengiraan nilai ambang untuk kitaran berikutnya. Sementara dalam LEACH, pemilihan ketua berdasarkan kepada algoritma pembahagian. Kedua-dua protokol telah dilaksanakan dalam simulator rangkaian untuk membandingkan prestasinya. Kajian menunjukkan prestasi yang baik dicapai oleh LEACH yang di ubahsuai berdasarkan keputusan yang diperolehi.

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LIST OF SYMBOLS AND ABBREVIATIONS

WSNs	-	Wireless Sensor Networks
CHs	-	Cluster Heads
BS	-	Base Station
LEACH	-	Low-Energy Adaptive Clustering Hierarchy
TDMA	-	Time Division Multiple Access
CSMA	-	Carrier Sense Multiple Access
MAC	-	Medium Access Control
OSI	-	Open System Intercopnnection
TCP/IP	-	Transmission Control Protocol/ Internet Protocol
FND	-	First node dead
HND	-	Half node dead
p	-	Desired percentage of cluster head
r	-	Current round
k	-	Number of cluster
$T(n)$	-	Threshold value for cluster head selection
n	-	Number of nodes
G	-	Number of node that not yet become cluster head
$E_{residual}$	-	Node residual energy
E_{total}	-	Network total residual energy
E_{TXelec}	-	Transmit energy consumption
E_{RXelec}	-	Received energy consumption
E_{amp}	-	Amplifier energy consumption

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Wireless Sensor Networks (WSNs) are widely used to create a smart environment that relies on sensory data from real world. The application of wireless sensor networks provides an enormous wirelessly connected infrastucture facilitating the function of monitoring a physical and enviromental conditions, such as temperature, sound, vibration, pressure, humidity, acidity, motion and pollutants. The advent of smart environments relies heavily on sensor network for data acquisition and dissemination whether in building, shipboard, intelligent transportation system, habitat monitoring, healthcare monitoring, home automation, traffic control, or elsewhere (Lewis F. , 2004) (Ali, Abdulmaowjod, & Mohammed, 2011). A smart sensor used in WSNs is a combination of sensing, processing and communication technologies.

The basic architecture of smart sensor is shown in Figure 1.1 Sensing unit is used to detect the changes of parameters in the network, signal conditioning responsible for smoothing the analog electrical signal before it is converted to digital domain. The resultant digital signal is used as the input to the application algorithm or processing unit and then cached in the memory. The transceiver is used to communicate with other sensors or base station (BS) which may act as an internet gateway in WSN (Ali, Abdulmaowjod, & Mohammed, 2011).

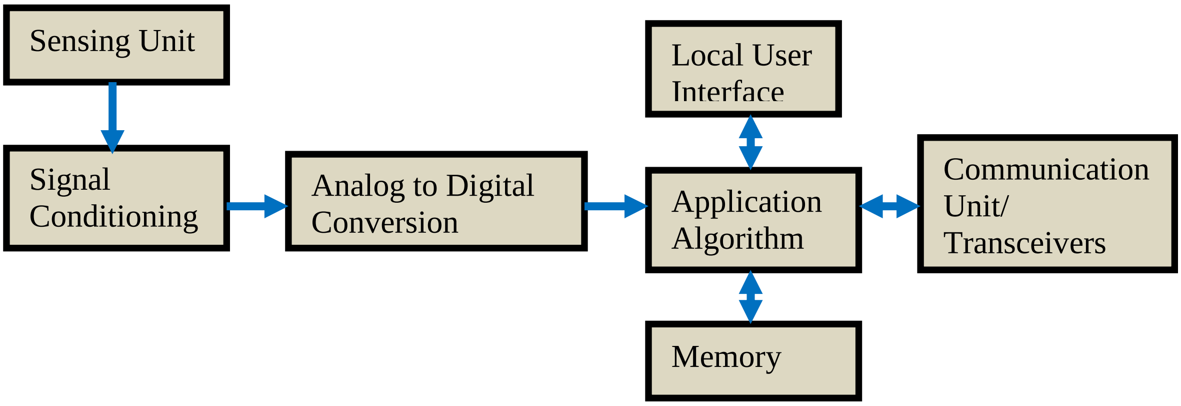

Figure 1.1: Smart sensor architecture

(Dietrich & Dressler, 2009) stated in their study stated that network lifetime is a key characteristic to evaluate a sensor network. The effectiveness of WSNs depends on the functionality of all sensors in the network. If the sensor node is active, it proceeds to perform a duty to sense, communicate and process information (temperature, humidity etc). There are two major factors that affect the network lifetime: how much energy it consumes over time and how much energy is available for the particular node. The proposed technique to deal with network lifetime called clustering, which is an important method. Additionally, a good performance WSNs is highly dependent on energy-efficient clustering routing algorithm (Liu, et al., 2010). The development involve a clustering-based hierarchy protocol that optimizes the energy-efficiency in WSNs is called Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman, Chandrakasan, & Balakrishnan, 2000).

1.2 Description

The aim of this thesis is a research about the network lifetime of WSNs. Using an appropriate algorithm in routing protocol, power consumption can be achieved. The research presented in this thesis focussed on the implementation of Low-Energy Adaptive Clustering Hierarchy (LEACH) algorithm within the WSNs routing protocol, in which original work and was introduced by (Heinzelman, Chandrakasan,

& Balakrishnan, 2000). Although LEACH algorithm provides an improvement in the network lifetime for WSNs, there are still areas that need to be developed so that more energy can be conserved. There are many researches that were conducted based on LEACH algorithm for example Energy LEACH (E-LEACH) (Xiangning & Yulin, 2007), Two-Layer LEACH (TL-LEACH) (Loscri, Morabito, & Marano, 2005), Centralize LEACH (C-LEACH) (Heinzelman, Chandrakasan, & Balakrishnan, 2002) and V-LEACH (Yassein, Al-zou'bi, Khamayseh, & Mardini, 2009).

In this thesis, some modifications were introduced based on LEACH algorithm and various performance comparisons were made to illustrate the improvements of this algorithm. Common features were maintained in the simulated network which were already present in the majority of the up-to-date WSN implementations. Furthermore, advanced features and parameters will be analyzed in order to obtain an energy consumption improvement. Therefore, it is essential to analyze and study the original LEACH algorithm through reviewing the literatures, building the simulation test-bed and performing the simulation on the existing algorithms. After that, the modification of LEACH will be implemented in the simulation test-bed and the most used simulation environments will be evaluated and analyzed.

1.2.1 Wireless sensor networks

According to definition given in (Sohraby, Minollil, & Znati, 2007),“A wireless sensor networks (WSNs) consists of densely distributed nodes that support sensing, signal processing, embedded computing, and wireless connectivity; sensors are logically linked by self-organizing means. WSN typically transmit information to collecting (monitoring) stations that aggregate some or all of the information. WSN have unique characteristics, such as, but not limited to, power constraints and limited battery life for the WNs, redundant data acquisition, low duty cycle, and, many-to-one flows.” Although the development of this kind of networks was initially for military applications, but nowadays they are used in many different industrial and civilian application areas, including industrial process monitoring and control, healthcare applications or traffic control. WSNs are composed of a set of sensor nodes, typically equipped with some sensors, a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. Therefore, these devices make up a network with sensing, data processing and routing capabilities.

1.2.2 Advantages of wireless sensor networks

Knowing about the advantages of WSNs, it is enough to be conscious of the wide variety of applications where WSNs are present. Typically, WSNs applications involved in some kind of monitoring, tracking, or controlling. Some of the numerous applications and the benefits that WSNs bring are:

i. **Environmental Monitoring:** watershed management, forest fire prediction or irrigation management. It helps to preserve and maintain the natural resources.
ii. **Structural Health and Industrial Monitoring:** machinery failure detection. It reduces the maintenance costs and prevents from catastrophic failures.
iii. **Civil Structure Monitoring:** health monitoring of large civil structures, like bridges or skyscrapers. It prevents from human catastrophes.
iv. **Medical Health-care:** telemedicine, remote health monitoring. Allows doctors in remote and rural areas to consult with specialists in urban areas, remote handling of medical equipment (tele-surgery), etc.

1.2.3 Drawbacks of wireless sensor networks

Although WSNs offer many advantages in a numerous application, there are several constraints which will affect directly the networks and devices' design. Some of the most significant constraints are:

i. **Power consumption**: this constraint affects directly on the nodes' operating lifetime. With energy-aware and transmitting power adjusting capacity protocols, the energy consumption can be highly reduced, and thus increased the network lifetime.

ii. **Self-configuration capability and good scalability**: this issue can be solved by choosing and implementing the suitable network protocol.

iii. **Fault tolerance**: if all the devices process the same signal (temperature, humidity, etc.), the network will offer replication in a native manner. If the devices do not develop the same function, the device replication can solve the fault tolerance problem, and this solution shouldn't affect the scalability due to the nature of the network.

This thesis proposed a mechanism to will counter the first drawback of WSNs which is the power consumption by designing and implementing the appropriate algorithm in a routing protocol.

1.3 Objectives

The main objectives of this thesis are:

i. To implement and simulate a wireless sensor networks (WSNs) using OMNeT++ network simulator.

ii. To implement a modified LEACH algorithm that solves the energy consumption problem in wireless sensor networks.

iii. To compare and evaluate the performance of the LEACH and modified LEACH in term of network lifetime.

1.4 Thesis Outline

As an introduction (Chapter 1), the motivation of the research and general description on WSNs including the advantages and drawbacks are presented in this chapter. Objectives of the research are also included as a guideline to complete this research.

Chapter 2 desribed the previous works of other researchers. The work on WSNs including the MAC protocol and the classification of WSNs are discussed in this chapter. Additionally, a comparison between various routing protocol are elaborated and the rationale for implementing LEACH protocol also identified.

Chapter 3 compare a number of network simulator that available to implement the proposed algorithm. An explanation of OMNeT++ simulator step by step done starting form building a network until running the simulation.

Chapter 4 explains abaout the implementation of LEACH algorithm and modified LEACH algorithm in OMNeT++ network simulator. Besides, the details abaout the algorithm are also included.

Chapter 5 is about the analysis and evaluation of results from the simulation. In the first section, the parameters for the simulation is explains. Second section is about the analysis of first node dead and half node dead to determine the improvement of network lifetime.

Chapter 6 concluded the thesis and proposed some areas for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

WSNs are increasingly deployed in a variety of applications, initially for military application and currently used in monitoring of medical conditions inside human body, monitoring the climate change and also used in reporting the mechanical stresses in building and bridges. A standard WSNs consists of a set of sensors that communicates to the external world via BS or sink. The sensors are autonomous small devices with several constraints like the battery power, computation capacity, communication range and memory. They include transceivers to gather information from its environment and pass it on up to a certain base station, where the measured parameters can be stored and available for the end user. Sensor networks are also energy constrained since the individual sensors, which the network is formed with, are extremely energy-constrained as well. The communication devices on these sensors are small and have limited power and range.

2.2 A wireless sensor network model

WSNs consist of a set of many sensors with sensing, wireless communication and computation capabilities. These sensors are scattered in the preserved environment and located far from users. The architecture of WSNs includes three entities as in (Karl & Willig, 2005). There are:

- Sensors which make up the network: its function is based on taking local measures through a discrete system, creating a wireless network in an unattended environment, gathering data and sending them to the final user through the BS.
- Base station or gateway node: it is located near the sensor field. The data or information gathered by the sensor field is sent to the base station through a multihop infraestructureless architecture, which communicates with the user via Internet or satellite communication.
- User: it is the entity interested in obtaining the information about a specific phenomenon by means of measuring or monitoring the environment.

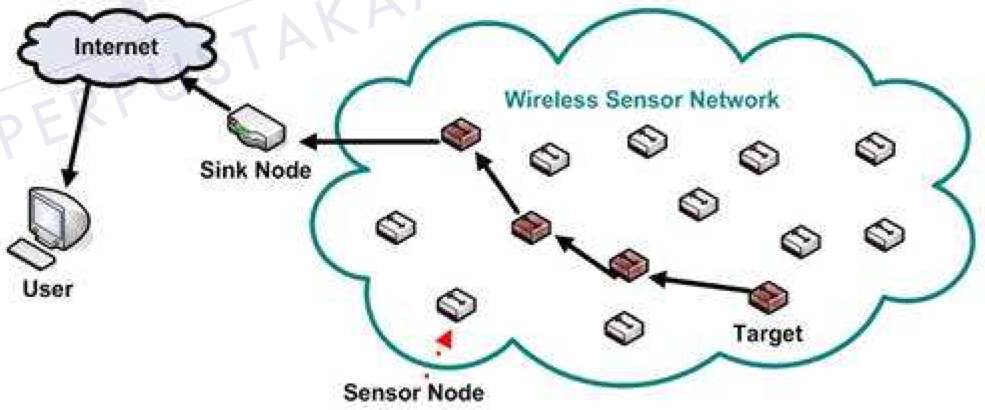

Figure 2.1: Wireless sensor network architecture

2.2.1 Protocol architecture

Protocol architecture is the layered structure of hardware and software that support the exchange of data between two systems. When communication is desired among computers from different vendors, the data must be transmit in the specific format because different vendors use different data format and data exchange protocols. The key fucntions normally performed by a protocol include encapsulation, segmentation and reassembly, connection control, ordered delivery, flow control, error control, addressing and multiplexing. There are two protocol architecture have served as the basis for the protocol standards which is TCP/IP and OSI model (Stalling, 2004). Figure 2.2 indicates the different between TCP/IP and OSI model.

<table>
<tr><th>TCP/IP</th><th>OSI</th></tr>
<tr><td rowspan="3">Application</td><td>Application</td></tr>
<tr><td>Presentation</td></tr>
<tr><td rowspan="2">Session</td></tr>
<tr><td rowspan="2">Transport (host-to-host)</td></tr>
<tr><td>Transport</td></tr>
<tr><td>Internet</td><td rowspan="2">Network</td></tr>
<tr><td rowspan="2">Network Access</td></tr>
<tr><td>Data Link</td></tr>
<tr><td>Physical</td><td>Physical</td></tr>
</table>

Figure 2.2: A comparison of the OSI and TCP/IP protocol architecture

2.2.1.1 OSI model

OSI model was developed by ISO which would allowed the exchange of data between various platform of different vendors. It has seven layers where each layer perform a certain internetworking function. The function of each layer described as follows:

i. **Physical Layer**: Transmits the bit stream over the physical medium.
ii. **Data Link Layer**: Provide reliable transfer of information.
iii. **Network Layer**: Provides transmission & switching technologies.
iv. **Transport Layer**: End-to-end error recovery and flow control.
v. **Session Layer**: Establishes, manages & terminates connections.
vi. **Presentation Layer**: Represent the data.
vii. **Application Layer**: Provides access to the OSI environment for users.

2.2.1.2 TCP/IP protocol architecture

The TCP/IP model organizes the communication task into five relatively independent layers:

i. **Physical Layer**: Physical interface between a data transmission device (e.g. computer) and a transmission medium or network. This layer concerned with the characteristics of transmission medium, signal level and data rates.
ii. **Network Access Layer**: Perform the data exchange between an end system. The destination address provision so thet the network can send the data to the appropriate destination.
iii. **Internet Layer**: Provides the routing function across multiple networks. This function uimplemented in the end system and routers.
iv. **Transport Layer**: This layer corcerned on end-to-end data transfer. The Transmission Control Protocol (TCP) is the most commonly used protocol to performed this functonality.
v. **Application Layer**: Support user application for example http, smtp and fttp.

2.2.2 MAC protocol

The MAC layer is a sublayer of the data link layer and it is used in networks where multiple machines need to communicate via a single communication channel. MAC layer must be energy-efficient to improve the network lifetime which become the main objectives of current research and study. In (Ye, Heidemann, & Estrin, 2001), there are several causes of energy waste corcerning MAC layer. There are are collisions, overhearing, control packet overhead, idle listening and overemitting.

Collisions consist on the reception of more than one packet at the same time which resulted in packets being dropped and retransmission was initiated. Overhearing occurs when a node receives packets destined to other nodes. The control packet overhead or the number of control packets should be minimized as far as possible in a data transmission. Idle listening is produced when a node listens to an idle channel to receive possible traffic. On the other hand, overemitting is caused by the transmission of a message when the destination node is not ready. A correctly-designed MAC protocol should avoid these facts in order to obtain the best performance and minimum energy consumption.

A survey done by (Demirkol, 2006) presented the advantages and disadvantages of several MAC protocols. These protocols are:

i. Sensor-MAC (S-MAC)

The basic idea of this MAC protocol consists on locally managed synchronizations and periodic sleep listen schedules based on these synchronizations. Nodes sleep and wake up periodically introducing the term of duty cycle. This MAC protocol shows a disadvantages when two neighbor nodes reside in two different virtual clusters which set up a common sleep schedule, they wake up at listen periods of both clusters.

Schedule exchanges are accomplished by periodical SYNC packet broadcasts to immediate neighbors. The period for each node to send a SYNC packet is called the synchronization period. A sample of sender-receiver communication is shown in Figure 2.3. Collision avoidance is achieved by a carrier sense, RTS/CTS packet

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